Vibration Reduction of Flexible Structures During Slew Operations*

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Vibration reduction of flexible structures during slew operations poses a challenging task. Slew of flexible structures arises in many situations such as attitude control of spacecraft with large solar array panels and rotation of flexible robotic manipulators. In this paper, a new approach for vibration reduction of flexible structures during slew operations is proposed. The new approach integrates the method of command input shaping and the technique of active vibration suppression. In this new approach, the method of command input shaping is used to modify the existing command so that less vibration will be caused by the command itself. The technique of active vibration suppression using smart materials is used actively to control the vibration during and after the slew. To verify this new approach experimentally, an apparatus of a flexible rotating beam with a smart material actuator and sensor was built. In this setup, two piezoelectric patches were bonded on the surface of the flexible beam near its cantilevered end and were used as the smart actuator and the smart sensor respectively. With this pair of smart actuator and smart sensor, a strain rate feedback (SRF) controller was designed for active vibration suppression. With the Zero Vibration Derivative (ZVD) shaper and the SRF controller, the proposed new approach can significantly reduce the vibration of the flexible beam during slew operations.

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1. INTRODUCTION

Slew of flexible structures arises in many situations such as attitude control of spacecraft with large solar array panels and rotation of flexible robotic manipulators. Vibration reduction of flexible structures during slew operations poses a challenging task. Research in this area has been taken along two directions: one direction concentrates on modifying the input command to reduce vibrations and the other concentrates on active suppression of the induced vibrations.

Notch filtering and input shaping[1] are two common methods used to modify the input command in order to reduce vibrations of flexible structures. Between of these two methods, input shaping has several advantages which makes it superior including effectiveness in vibration cancellation, robustness to variations in modal frequency and damping ratio, and suitability for multiple-mode systems.[2]

One promising method for actively suppressing the induced vibrations is to use piezoelectric materials as actuators since piezoelectric materials have the advantages of high stiffness, light weight, low power consumption and easy implementation. A wide range of approaches has been proposed for using piezoelectric material to actively control vibration of flexible structures. Strain Rate Feedback (SRF) control was used for active damping of a flexible space structure.[3] In this approach, the structural velocity coordinate is fed back to the compensator and the compensator position coordinate, multiplied by a negative gain, is fed back to the structure. Positive position feedback (PPF)[4] has also been used to provide damping for a particular mode. Linear Quadratic Gaussian (LQG) design[5] and fuzzy control[6] have also been used. The H_∞ control was applied to flexible structures which have uncertainty in the modal frequencies and damping ratios.[7] Other methods include Model Reference Control (MRC), phase lead control[8] and etc. Among these approaches, SRF has a wider active damping region and can stabilise more than one mode given a sufficient bandwidth. SRF is also easy to implement.

In this paper, a new approach integrating command input shaping and strain rate feedback control is proposed for vibration reduction of flexible structures during slew operations. In this new approach, the method of command input shaping is used to modify the existing command so that less vibration will be caused by the command itself. The technique of strain rate feedback control for active vibration suppression using smart materials is used to actively reduce the vibration during and after the slew. An apparatus of a flexible rotating beam with a smart material actuator and sensor was built to verify this new approach experimentally. In this setup, two piezoelectric patches are bonded on the surface of the flexible beam near its cantilevered end and are used as the smart actuator and the smart sensor respectively. With this design, a transducer pair consisting of a smart actuator and a smart sensor, produces a strain rate feedback (SRF) controller for the active vibration suppression. With the Zero Vibration Derivative (ZVD) shaper and the SRF controller, the proposed new approach can significantly reduce the vibration of the flexible beam during slew operations.

2. EXPERIMENTAL SETUP

A schematic of the equipment setup is shown in Fig. 1. A flexible E-glass composite laminated beam is fixed onto a shaft driven by a high-torque DC motor which is supported by a square platform. The DC motor is equipped with an optical encoder to sense the angular position. Piezoelectric material, in particular PZT (Lead Zirconate Titanate), is used for both sensors and actuators in this research. The composite beam has a width of 0.0506m, thickness of 0.0032m, length